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NO 6

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 309

JOINT REPORT ON STANDARDIZATION TESTS ON N. P. L. R. A. F. 15 AIRFOIL MODEL

By WALTER S. DIEHL

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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By WALTER S. DIEHL
Bureau of Aeronautics

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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JOINT REPORT ON STANDARDIZATION TESTS ON N. P. L. R. A. F. 15 AIRFOIL MODEL

By Walter S. Diehl

SUMMARY

This report contains the wind-tunnel test data obtained in the United States on a 36 by 6 inch R. A. F. 15 airfoil model prepared by the British Aeronautical Research Committee for international trials. Tests were made in cooperation with the National Advisory Committee for Aeronautics at the Bureau of Standards, Langley Memorial Aeronautical Laboratory, Massachusetts Institute of Technology, and McCook Field.

In addition to brief descriptions of the various wind tunnels and methods of testing, the report contains an analysis of the test data. It is shown that while in general the agreement is quite satisfactory there are two cases in which it is unsatisfactory. Since the lack of agreement in the latter is probably explained by errors known to be inherent in the methods of determining and applying corrections in these particular tests, it is concluded that the agreement obtained is more a matter of technique than a wind-tunnel characteristic.

INTRODUCTION

During the early development of experimental aerodynamics it was found that test data on the same wing section from different wind tunnels frequently showed rather large and important lack of agreement that could not be ignored. This condition led many engineers to distrust all wind-tunnel test data and for many years prevented the wind tunnel from receiving the attention and credit it deserves. The situation has been greatly improved in recent years owing to the general adoption of more careful test methods and the application of corrections now known to be necessary. Since it is a matter of some interest, a few of the more important advances will be discussed briefly.

The early attempts which were made to find the cause or causes of lack of agreement in wind-tunnel tests on airfoil models centered chiefly on interference effects from the method of attachment to the balance. One of the first papers on this subject is an appendix to a report by Bairstow, Pannell, Lavender, Fage, and Cowley.[1] It was pointed out in this paper that the so-called "crank-spindle" method of attachment was unreliable. Concerning this, the report says, "We have been unable to find any means of supporting a model airfoil from its center which does not involve disturbance of flow of air round the aerofoil to a considerable extent; with the best of such arrangements we have yet found the residual correction after subtracting the resistance of the spindle alone is of the order of 20 per cent on the minimum drag." The next important paper on the subject is by Pannell and Campbell.[2] By this time it was generally recognized that unless great precautions were taken, good agreement could not be obtained in tests on the same model with different methods of support in the same wind tunnel, while good agreement between two tunnels using the same method of supporting the model was disappointingly rare. It is to be emphasized that in this phase of wind-tunnel development the chief sources of error may be ascribed to lack of familiarity with the equipment and with the fundamental aerodynamic laws involved. As the technique of testing improved there was a noticeable improvement in test data as shown by better agreement between the results in the various tunnels.

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[1] Experiments on the Variation of the Forces and Moments on an Airfoil as the Speed Changes. British Advisory Committee for Aeronautics Reports and Memoranda No. 148, March, 1915.

[2] Pannell, J. R., and Campbell, N. R., Methods of Support for Models During the Measurement of their Aerodynamic Resistance. Br. A. C. A. R&M No. 244, July, 1916.

Further efforts to improve the quality of test data led to a rather general adoption of the Göttingen wire balance[3] with its greatly reduced interference effects from the model supports. This type of balance has been found very satisfactory and although the drag correction is quite large it may be determined with considerable accuracy when proper care is used.

In 1919 ("Tragflugeltheorie" Göttingen Nachrichten) Prandtl[4] gave the corrections for tunnel-wall interference, but it was not until about 1924 that these corrections were generally known to bring most of the discordant test results into good agreement. Glauert[5] appears to have given the first experimental verification of the validity of the wall-interference correction. In a subsequent paper[6] he demonstrated in a very striking manner how effective these corrections are in bringing test data into agreement.

The combination of improved technique and wind-tunnel equipment, with the general application of wall effect corrections, removed practically all doubt concerning the validity of wind-tunnel test data, but it appeared desirable to conduct comparative tests on the same model in different wind tunnels on order to establish some measure or idea of the normal variations encountered. This project was proposed by a number of investigators, but no definite action was taken until the British Aeronautical Research Committee decided to prepare a series of models for international trials. The inception and purpose of the International Trials are fully explained in R. and M. No. 954[7] from which the following statement is quoted: "Acting on a suggestion made by the Director of Research, the Aeronautical Research Committee decided in March 1920, to institute comparative model tests in as many as possible of the aerodynamic laboratories of the world. It was thought that such tests, in which the same models would be tested successively by all laboratories, would supply valuable information which had not previously been available. The aim of wind-tunnel experimental work is to obtain reliable estimates of the forces which would be experienced by bodies moving at specified speeds through still air of infinite extent; but in practice it is necessary to hold the model stationary and to generate a flow of air past it and measurements made in this way are in some degree open to question, in that the forces imposed upon the model may be affected (1) by the limited extent of the air stream in which they are placed and (2) by the turbulence which can never be entirely eliminated. The results must furthermore depend to some extent upon the methods adopted for connecting the models to the measuring apparatus. Different methods are adopted in different countries, and wind tunnels of varying size and design are employed; thus there is some uncertainty as to the extent to which a comparison can be made—e. g., between different aerofoils tested in different countries—and this uncertainty, it was thought, would be reduced if comparative figures were available from tests upon the same models.

"It was at first intended that the proposed international trials should comprise:

"(1) Determination of lift, drag, and center of pressure for a standard aerofoil model at various angles of incidence.

"(2) Resistance measurements at zero angle of yaw on a very good streamline airship model.

"(3) Tests of a complete aeroplane model, including complete determination of forces and moments, and of the more important stability derivatives.

"At a later date it was decided to delete the third test, and under the second heading to test two models differing by the amount of parallel portion included between head and tail. Invitations to participate in these trials were sent to the authorities in U. S. A., France, Italy, Holland, Canada, and Japan, and were in every case accepted. A model aerofoil and two airship models were constructed at the National Physical Laboratory, and after preliminary tests in Great Britain, these models were sent abroad, the aerofoil in the first instance to France and the airships to U. S. A.

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[3] For a description see Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen, 1921.

[4] See also Prandtl, Applications of Modern Hydrodynamics to Aeronautics. N. A. C. A. Technical Report No. 116 (1921).

[5] H. Glauert, Experimental tests of the Vortex Theory of Airfoils. Br. Aeronautical Research Committee Reports and Memoranda No. 889, November, 1923.

[6] H. Glauert, An Experimental Test of the Prandtl Correction for Tunnel Wall Interference. Br. A. R. C. R. and M. No. 898, January, 1924.

[7] International Trials—Report of Aerofoil Tests at National Physical Laboratory and Royal Aircraft Establishment. Br. A. R. C. R. and M. No. 954, May, 1925.

"It was at first contemplated that no report should be published until all the laboratories had completed their measurements, so that an exhaustive comparison of the results could be made. But the length of time involved in these trials, where every refinement which experience can suggest is being employed by the collaborating establishments, suggests that a different procedure is desirable, and it has recently been decided to invite each participating nation to publish an account of its own tests, the intention being that when the whole series is complete some critical summary shall be prepared and published by the A. R. C."

The airfoil model was received by the N. A. C. A. in 1923, and tests were made during the latter part of 1923 and the early part of 1924. Owing to the limited time available it was not feasible to make tests at more than four laboratories, as follows: Bureau of Standards, Langley Memorial Aeronautical Laboratory, Massachusetts Institute of Technology, and McCook Field. This report is a compilation of the data contained in the reports from these laboratories.

There appears to have been some misunderstanding regarding the nature of the tests, which, according to the quotation from the British report given above, were supposed to be made with unusual accuracy, while it was agreed that the tests in this country should be made in the routine manner. The model was supplied to each of the four laboratories without specification as to method of support, wind speed to be used, etc. In other words, no restrictions whatever were imposed. Consequently, there is a lack of uniformity in test speeds, but it is felt that, with one exception to be noted later, the results may be considered as quite fairly representing the average test at each of the four laboratories.

DESCRIPTION OF WIND TUNNELS

Brief descriptions of the four wind tunnels have been compiled from the test reports. It is believed that these descriptions will prove to be of value in any interpretation of the test data.

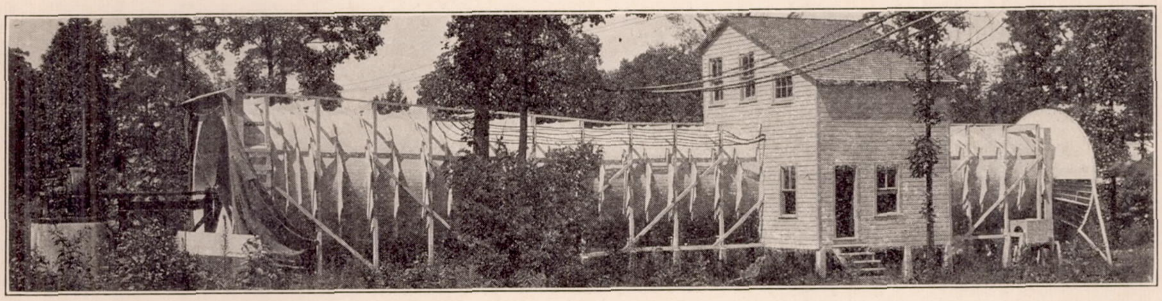

FIGURE 1.—Bureau of Standards wind tunnel

BUREAU OF STANDARDS: The 10-foot outdoor tunnel was used in these tests. This tunnel is of circular cross section with a total length of 84 feet, divided into a cylindrical section 10 feet in diameter by 50 feet in length and an exit cone which expands to a diameter of 14 feet 2 inches at the exit end. A honeycomb with cells 4 by 4 by 12 inches deep is installed at the entrance to the cylindrical section and a short faired intake is fitted immediately in front of the honeycomb. The axis of the tunnel is 8 feet above the ground and the distance from the honeycomb to the working section is approximately 27 feet. The propeller has 4 blades, 14 feet diameter by 9.8 feet pitch, and it is directly connected to a 200 HP. electric motor. The maximum R. P. M. is about 550, giving a wind speed of about 70 miles per hour. Figure 1 shows the general external appearance.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY: This wind tunnel is fully described in N. A. C. A. Technical Report No. 195,[8] from which the sectional view (Fig. 2), is taken. The over-all length is approximately 51 feet, divided into a 15 foot 9 inch entrance cone, an 11 foot 2 inch cylindrical test section, and a 24 foot 10 inch exit cone. The cross section is everywhere circular, and the throat diameter is 5 feet. The flow is effectively straightened by three honeycombs and a torque reactor. One of the honeycombs is located at the mouth of the entrance

[8] Elliott G. Reid, Standardization Tests of N. A. C. A. No. 1 Wind Tunnel (1924).

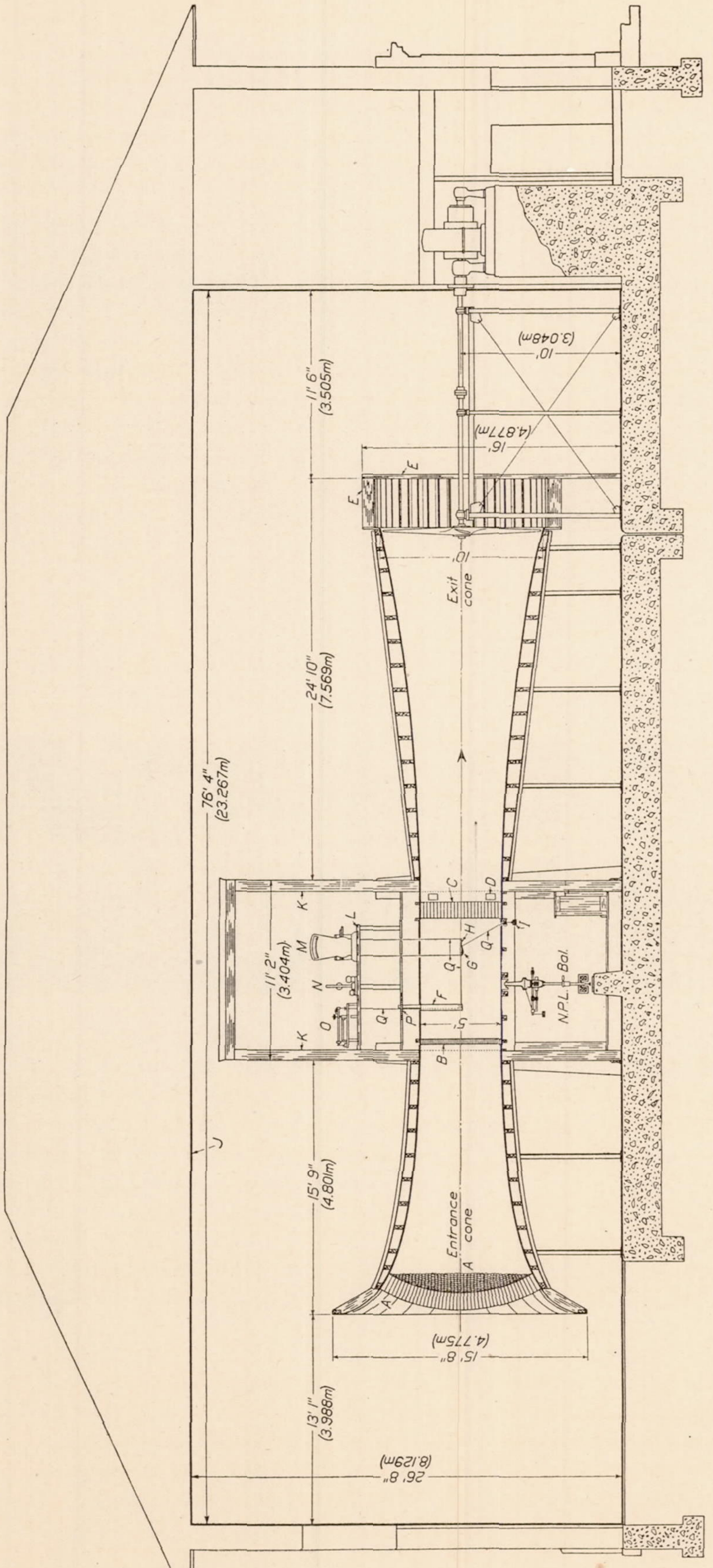

FIGURE 2.—National Advisory Committee for Aeronautics atmospheric wind tunnel

cone and the other two are at the ends of the cylindrical test section. These devices result in an exceptionally smooth and steady flow.

The 4-bladed 10-foot propeller is directly connected to a 200 HP. D. C. motor.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY: The 7.5-foot wind tunnel which was used in these tests is of the closed Venturi type (fig. 3), consisting of an experimental section 7.5 feet in diameter by 15 feet in length, an elliptically flared entrance 15 feet in diameter at the

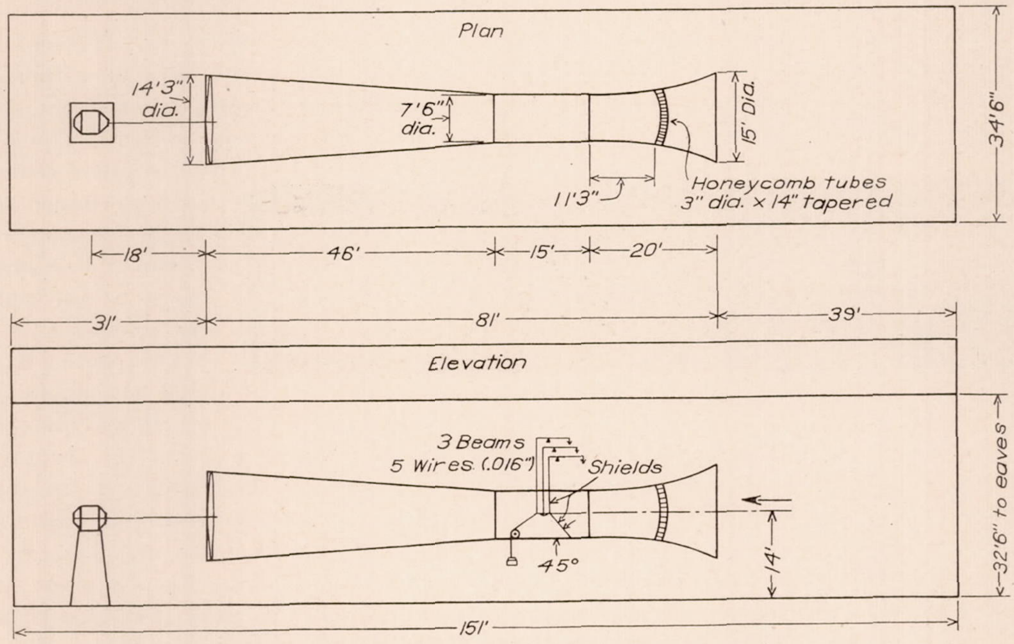

FIGURE 3.—Massachusetts Institute of Technology wind tunnel

mouth by 20 feet in length, and a straight tapered exit cone with a maximum diameter of 14 feet 3 inches and a total length of 46 feet. The honeycomb, which is located approximately midway in the entrance cone, is built up from tapered tubes 3 inches in diameter by 14 inches in length.

A 4-bladed propeller 14 feet 1 inch in diameter is directly connected to a 100 HP. electric motor. A wind speed of 60 feet per sec. is given at 300 R. P. M., using about 12 horsepower.

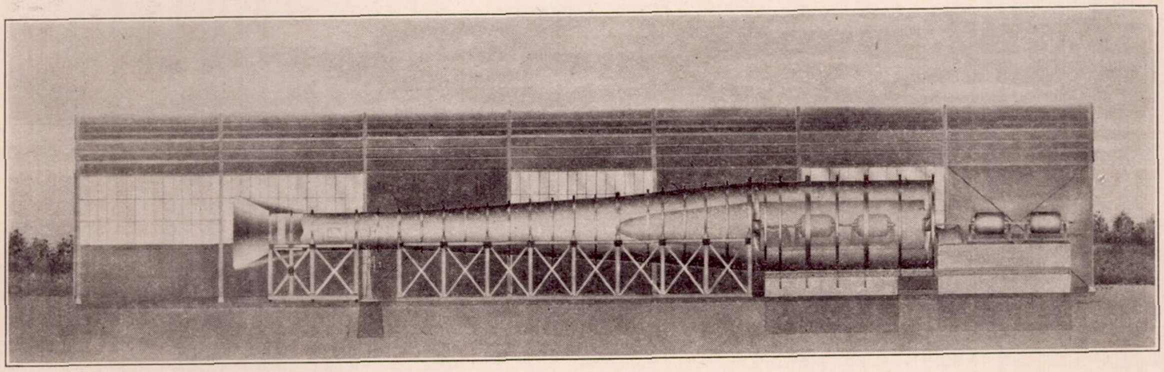

FIGURE 4.—McCook Field wind tunnel

McCOOK FIELD: The 5-foot tunnuel used in these tests has a cylindrical test section 18 feet long, a flared intake 10 feet in diameter by 11.25 feet in length, and a 2-piece exit cone 14 feet maximum diameter by 68 feet over-all length. The exit cone has a straight taper from 5 feet to 14 feet diameter in the first 44 feet of its length. The remaining length is cylindrical to accommodate the tandam propeller drive. The center line of the tunnel is 10 feet above the floor. A honeycomb built up of hexagonal tubing 4 inches across the flats and 20 inches long is located near the entrance of the test section and an air-flow straightener, consisting of 16

radical vanes, is mounted at the entrance of the intake cone. The balance is located 11.25 feet from the honeycomb. Two propellers, 11 feet 11 inches diameter, are driven by 600-HP. motors. A wind speed of 150 M. P. H. is obtained at 900 R. P. M. Many of the details are shown in Figure 4.

DESCRIPTION OF MODEL

The international standard R. A. F. 15 airfoil was of rectangular plan form, 6-inch chord by 36-inch span. The material was aluminum or aluminum alloy.

The condition of the model was a cause of some concern at each laboratory. The comments of the Bureau of Standards were as follows: "The model in its journey received rather severe treatment. Fifty-six holes had been drilled in various parts of it by testing laboratories, the condition of the surface was rather poor, and the model as a whole was warped and bent. The contour of the model as received was determined by the Gauge Section of the bureau. The angle of attack at the right tip was greater than that at the center by 0.35° while the angle at the left tip was greater than that at the center by 0.10° * * *. The value of the comparison of the measurements of lift and drag in different wind tunnels has been greatly reduced by the changes in the shape of the model." The comments from the Langley Memorial Aeronautical Laboratory were similar: "The model had been tested in several laboratories before reaching Langley Field and bore evidences of its travel * * *. While the holes, slots, etc., already in the wing were carefully filled with wax, the surface was considerably rougher than that of a new, carefully made airfoil and, as the ordinates were not measured here, it is possible that some distortion may have passed unnoticed. Comparison of the test results with those from slightly smaller R. A. F. 15 airfoils would indicate, however, that no distortion of major importance existed, and that the surface irregularities may have been responsible for the minimum drag being higher than expected."

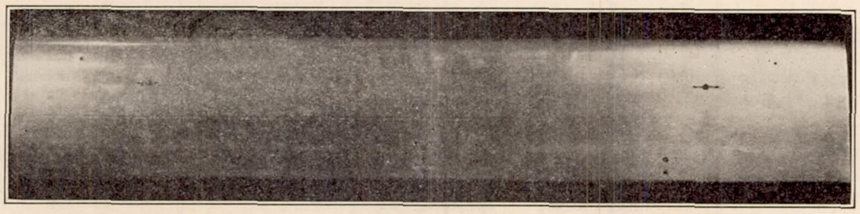

FIGURE 5.—Airfoil plan

The condition of the model which led to the foregoing comments is clearly shown by the photographs made at Langley Field. (Figs. 5 and 6.) The ordinates as measured by the Gauge Section of the Bureau of Standards are given in Table I. In addition to the ordinates the Bureau of Standards measured the curvature along the span at the maximum ordinate and found the following distortion:

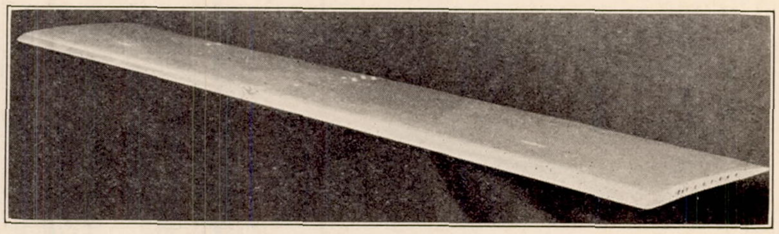

FIGURE 6.—Airfoil ¾ front view

Distance from right end, inches	0	6	12	18	24	30	36
Height above center, inches	0.161	0.073	0.022	0	0.024	0.083	0.139

Attention is invited to the fact that none of the distortions noted is very serious and that the effect on comparative tests should be negligible so long as no changes occur from one laboratory to the next. The latter condition may be expected to have been substantially met in the tests under discussion.

METHODS OF TESTING

Brief descriptions of the methods of holding the model and applying corrections have been compiled from the test reports.

BUREAU OF STANDARDS: A simple wire balance employing different set-ups for lift and drag measurements was used. For lift measurement the airfoil was suspended by four

parallel wires in the inverted position from a framework mounted on direct reading scales. The pair of wires on each wing tip were 3 inches apart and 20 inches long. The angle of attack was varied by tilting the framework. At ordinary angles the model was very steady, and a moderate yawing motion would give only a very small variation in the balance reading. Drag was taken by the shift link of the balance so that only the vertical component of the force was read. Measurements were not attempted at the angle of maximum lift or higher on account of violent yawing motions, nor were they extended to zero lift in the inverted position because of the danger to the model. A few measurements were made at negative angles with the airfoil right side up.

For drag measurements the wires were spread at the top in a plane perpendicular to the wind direction in order to reduce the yawing motion to a negligible amount. The model was allowed to swing downstream until the moment of the weight plus the vertical component of the air force balanced the moment of the horizontal component. The displacement of the model was measured by a sliding telescope and the total horizontal force computed. The correction due to the drag of the 0.0324-inch diameter wires used in the suspension was computed and amounted to about 75 per cent of the minimum drag.

Angles of attack were determined as follows: A steel straightedge 42 inches long was clamped tightly to the airfoil and the distance from each end to the floor of the tunnel measured. The angle of the airfoil to the floor with the straightedge attached was thus determined. Subsequent to the force measurements a small mirror was mounted on the surface of the airfoil and the change in angle due to the addition of the straightedge and the change due to air loads were measured by an optical method, thus determining the angle under which the forces were measured. The inclination of the wind stream and the alignment of the balance were determined from readings with the airfoil right side up and inverted. Readings were taken at wind speeds of 40, 57.5, and 100 feet per second.

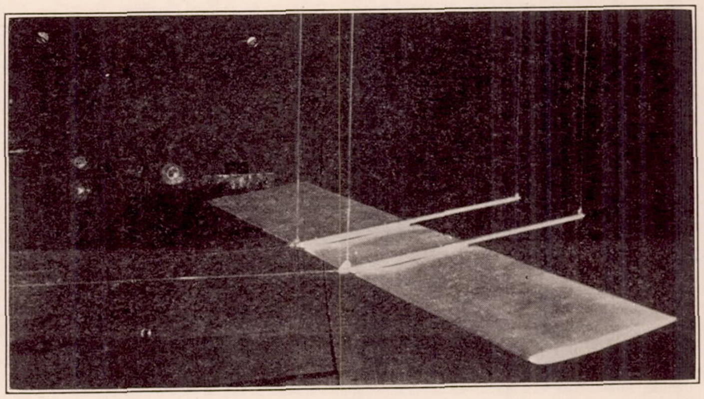

FIGURE 7.—Langley Memorial Aeronautical Laboratory (N. A. C. A.) wire balance

LANGLEY MEMORIAL AERONAUTICAL LABORATORY: The model was supported on the wire balance shown in the Figure 7. The skids upon which the wing rested were symmetrically disposed, 8 inches apart. The wire sizes were as follows: Front lift 0.023 inch, rear lift 0.013 inch, drag 0.013 inch, counterweight 0.013 inch for erect runs and 0.023 inch for inverted runs.

The wire drag correction was determined by successively replacing the wing with two different lengths of drill rod of the same diameter and subtracting from the drag readings taken on one of these combinations the drag of the rod as calculated from the differences between the two sets of data. Tests were made with a third skid mounted at midspan in an attempt to detect any interference or variation of support drag with angle of attack, but no perceptible change was found. The maximum change in angle of attack caused by the application of air load was measured and found to be less than 3 minutes for angles of attack below 10°. The total drag correction amounted to about 72 per cent of the minimum measured drag at 10 meters per second.

Balance readings are corrected for variation of forces in the static suspension with angle of attack, in addition to the support drag correction. Moments are computed not about the leading edge but about a point one-eighth inch below the leading edge on the skid center line, since this procedure simplified the computations and introduced no appreciable error except in the immediate neighborhood of zero moment.

29556—29——2

MASSACHUSETTS INSTITUTE OF TECHNOLOGY: A wire balance having the same general arrangement as the Göttingen balance, but greatly modified in detail, was used. The model is supported by two lift wires and one moment wire and is normally inverted. The lift wires are attached to small fittings 18 inches apart in the leading edge and the moment wire is attached to a sting on the center line of the model at a point 10 inches aft of the plane of the lift wires. The two lift wires lead to a cross arm mounted on a simple balance beam above the tunnel; the moment wire leads direct to another simple balance beam. The sum of the tensions in the lift and moment wires is the total lift on the model while the moment about the leading edge is given directly by the moment leading.

Drag is taken by two horizontal wires attached to the lift wire fittings. These horizontal drag wires are carried forward to a small fitting from which are led two wires, one vertical and the other inclined upstream and downward at 45°. This arrangement gives a load in the vertical wire exactly equal to the drag, while effectively preventing any yawing oscillation. The two vertical wires pass to a cross arm mounted on the third balance beam.

The angle of attack is varied by reeling the moment wire in or out on a drum, and the system is kept in tension by a single counterweight which is attached to a wire running down and back over a pulley. The effective wire drag is found by substituting for the wing a form of known drag, as measured at the same speed in this tunnel on a bell-crank balance. Since the wires are shielded by streamlike guards, the total wire-drag correction is of the order of 65 per cent of the minimum drag of good 36 by 6 inches wing model. Two calibrations are necessary to compensate for the stretch of the wires under load; the first is a direct drag calibration made by applying known drags to the model, and the second is a change in the first calibration caused by known lifts. A small correction for the effect of inclination in the moment wire at large angles of attack is necessary.

McCOOK FIELD: An N. P. L. type of balance was used in the McCook Field tests. This balance is well known and needs no further description here. (See E. P. Warner and F. H. Norton, Wind Tunnel Balances—N. A. C. A. Technical Report No. 72.) Normally the model is supported vertically by a spindle in the lower end, but tests were also made in this case with the model horizontal. In order to eliminate the effect of air-stream inclination the model was inverted in each position and the mean taken of the two readings.

In the vertical position three operators were employed to obtain best results. One operator observes the Wahlen gage, which is sensitive to one-tenth of 1 per cent in velocity head, and controls the speed while the other two operators read lift and drag. Moment readings were not taken simultaneously with lift and drag. Tare tests included spindle drag using the dummy-spindle method and deflection measurements.

TEST RESULTS

Test results are given in Tables II to X, inclusive. These data may be divided into three groups representing test speeds of approximately 35, 60, and 100 ft. per sec. Following this grouping the data are plotted in Figures 8 to 19, inclusive. The data in each group are plotted on polar diagrams with and without wall correction and also against angle of attack, with and without wall correction.

The correction for wall effect is made by the Prandtl[9] formulas

$$\Delta C_D = \frac{C_L^2 S}{2\pi D^2} = \frac{C_L^2 S}{8A}$$

and

$$\Delta \alpha = \frac{57.3\ C_L S}{2\pi D^2} = 7.16\ \frac{C_L S}{A}$$

where S is the area of the model, D the diameter of the wind tunnel, and A the cross-sectional area of the wind tunnel. These corrections are added to the drag and angle of attack observed in a wind tunnel having a closed test section.

[9] L. Prandtl, Applications of Modern Hydrodynamics to Aeronautics. (N. A. C. A. Technical Report No. 116.)

DISCUSSION OF TEST DATA

Consider the first group consisting of tests made at speeds between 29.3 and 40 ft. per sec. The polar plot of drag uncorrected for wall effect is given on Figure 8. The same data corrected for wall effect are plotted on Figure 9. Comparing these two figures it is seen that the wall-

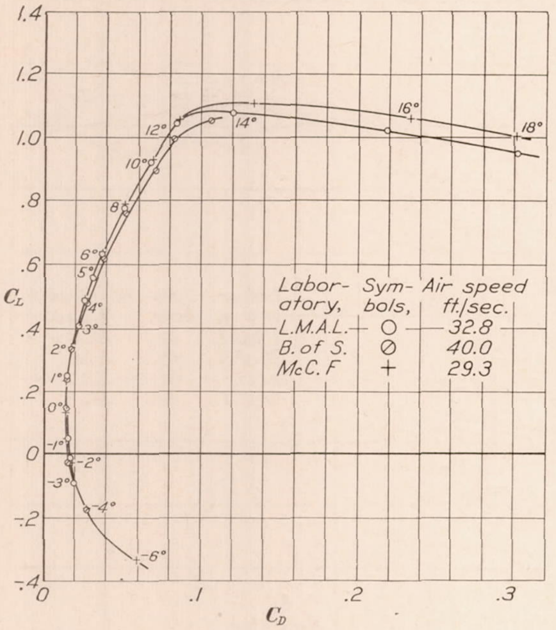

FIGURE 8

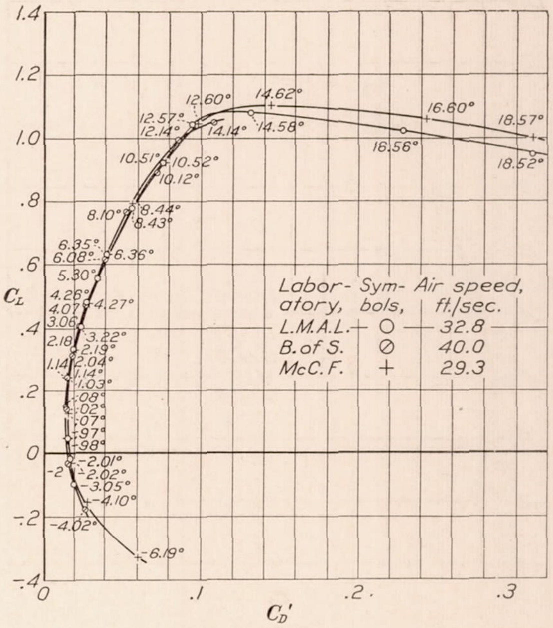

FIGURE 9

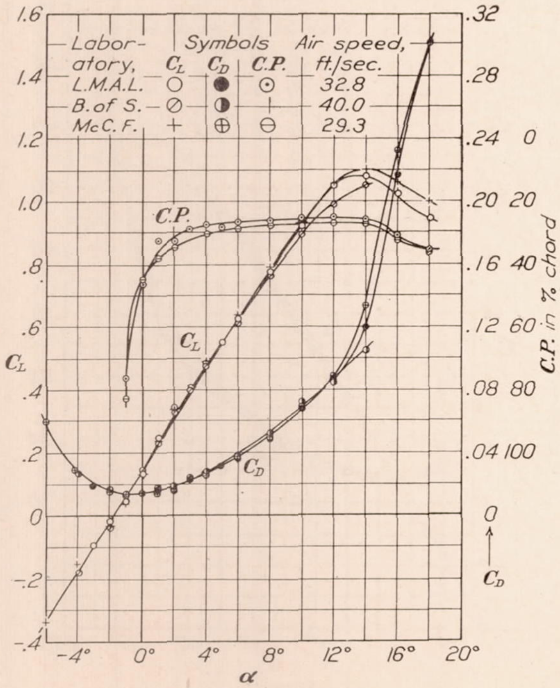

FIGURE 10

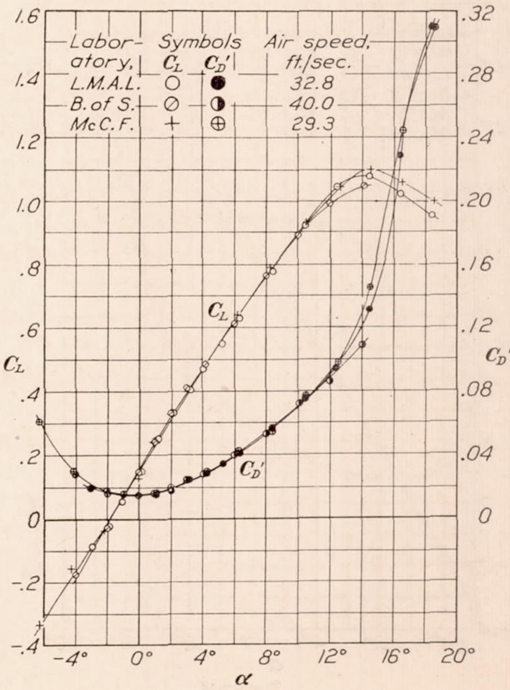

FIGURE 11

effect correction results in better agreement. The same conclusion may be reached from a study of these data plotted against angle of attack as in Figures 10 and 11.

The second group of tests were made at speeds between 57.5 and 65.6 ft. per sec. The polar plot of uncorrected data (fig. 12) shows greater divergencies than does Figure 8, but

most of the discrepancies are ironed out when the wall effect correction is applied, as shown in Figure 13. The two outstanding differences from mean values are the high maximum lift obtained in the McCook Field tests and the low minimum drag obtained in the Massachusetts Institute of Technology tests. These will be discussed later.

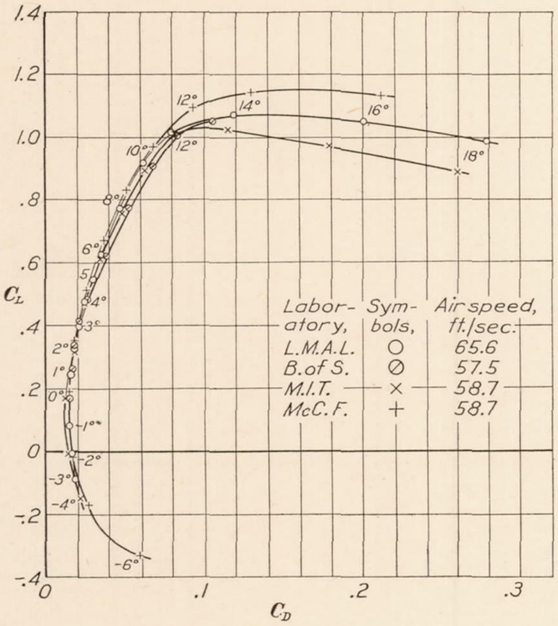

FIGURE 12

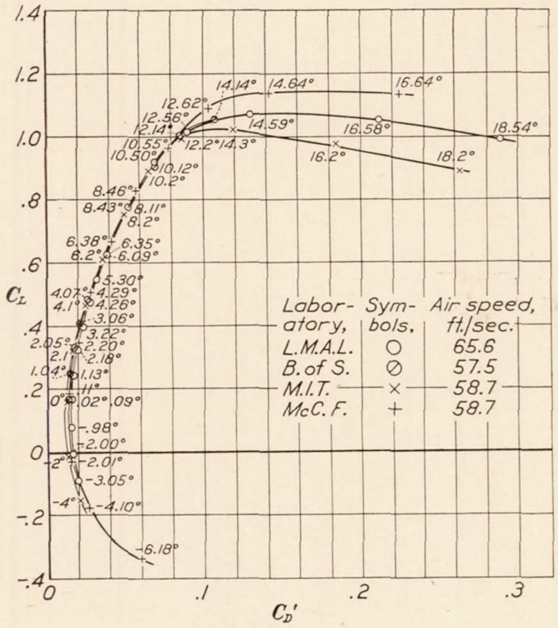

FIGURE 13

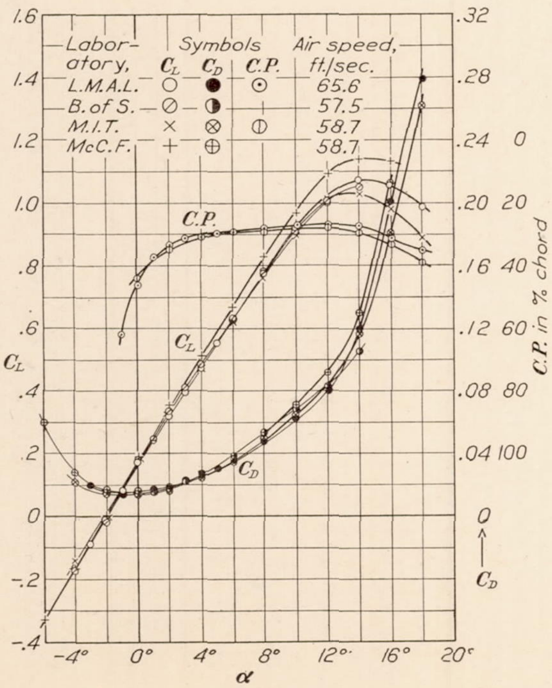

FIGURE 14

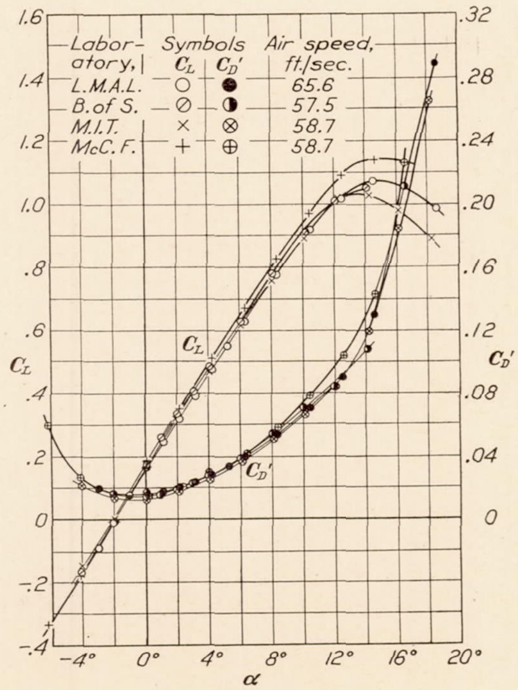

FIGURE 15

The third group consists of only two tests, one at 98.4 ft. per sec., the other at 100 ft. per sec. In this group the polar plots (figs. 16 and 17) show close agreement, but the plot against angle of attack (figs. 18 and 19) show some differences. The agreement is improved, however, by applying the wall interference correction.

A summary of the test data given in Table XI brings out the general points of agreement or divergence. These will now be considered individually, using the corrected test data only.

I. Maximum Lift.—The values of $C_{L}max$ range from 1.040 to 1.153, but the McCook Field values of 1.110 and 1.153 look questionable. If these be neglected, the variation is from

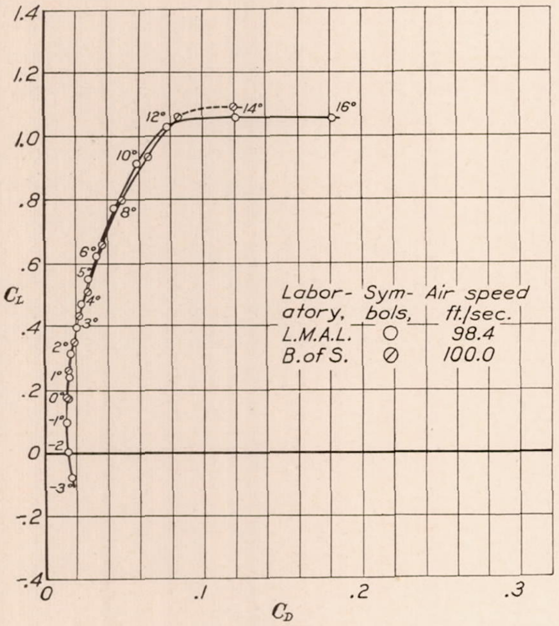

Figure 16

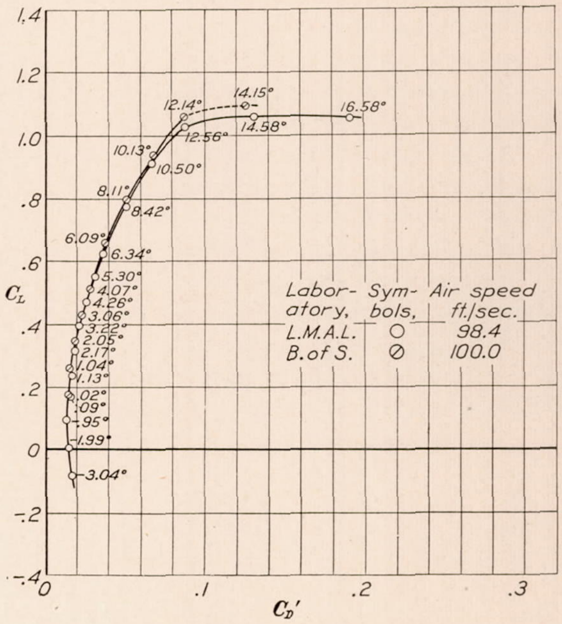

Figure 17

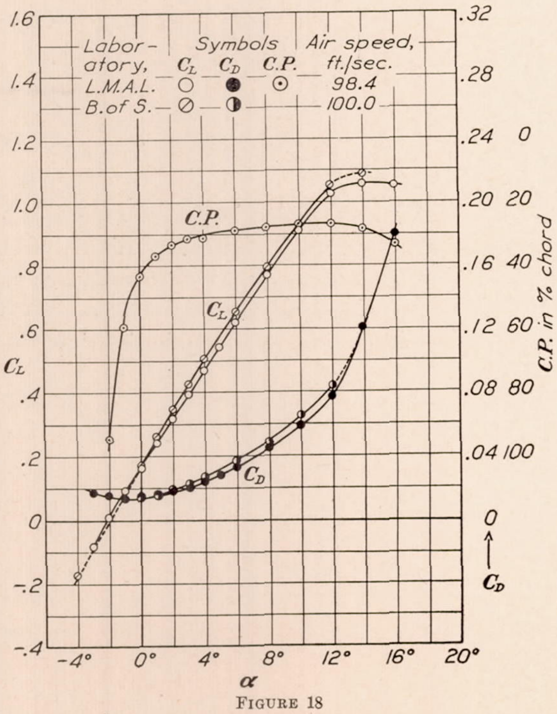

Figure 18

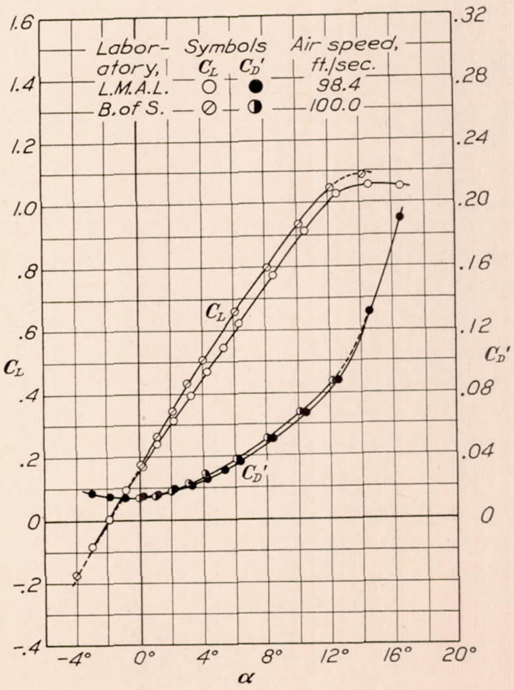

Figure 19

1.040 to 1.093. This must be considered reasonable agreement in this quantity which is sensitive to a number of factors, some tending to increase, some tending to decrease the observed value. In this case, the characteristics at high angles of attack in the McCook Field test at 40 miles per hour were determined with the model attached horizontally at its center to the

spindle of the N. P. L. type balance. This type of attachment is known to yield very unreliable results and the agreement obtained, though not close, speaks well for the care used in measuring the corrections in this case. In the tests at 20 miles per hour the model was held vertically by an end spindle and the average of the readings taken at a limited number of angles was used to determine the correction at all angles for spindle drag interference. This procedure is considered inadvisable, since there is no assurance that the correction does not vary erratically. The general practice is to determine the correction at each angle of attack. The report does not mention a correction for spindle lift and it is assumed that none was applied. This may partially explain the high maximum lift since this correction normally reduces the measured lift.

II. Minimum Drag.—With the exception of the M. I. T. value, the agreement in minimum drag is very good. While the values of $C_{D\ min}$ range from 0.0138 to 0.0147, part of the variation is due to scale effect as shown by the plot of $C_{D\ min}$ against test speed on Figure 20. $C_{D\ min}$ would be expected to vary along a curve similar to the dotted line shown on this figure.

In regard to the low value of $C_{D\ min}$ obtained in the M. I. T. tests, the report from this laboratory contains the following statement: "The test on this airfoil was made in a routine manner, no extra preparation being made or precautions beyond those regularly taken being used. It is felt that the proper comparison is between routine tests and not between those of a highly specialized nature." Readings were taken at intervals of 2° over the entire angular

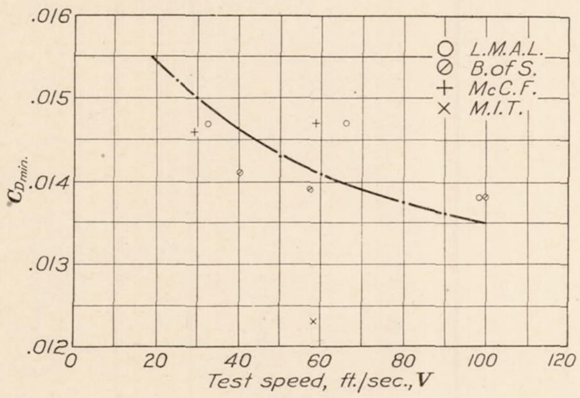

Figure 20

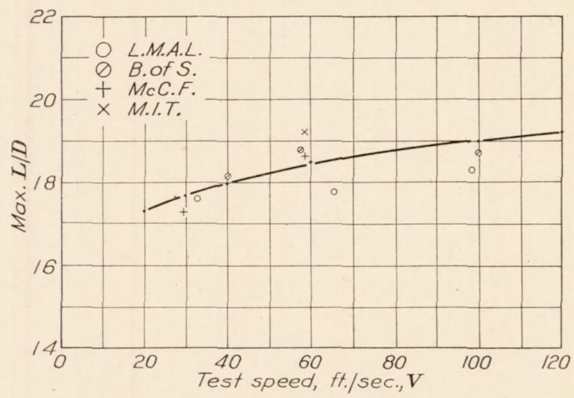

Figure 21

range of the tests, and the drag correction of the wire balance was determined by attaching a streamline rod the drag of which had been measured on a bell-crank balance. This at best gives only a close approximation to the wire drag correction, and some doubt naturally exists as to the accuracy in this case. In the Langley Field tests the wire drag correction was determined by testing two lengths of the same size rod on the wire balance, thus eliminating the attachment interference involved in the bell-crank balance.

After allowance has been made for different methods of holding the model and the general difficulty of securing great accuracy in measuring a low minimum drag, it is believed that a variation of more than 5 per cent from the mean should be considered excessive. It is generally agreed that in order to obtain accurate minimum drag data, the drag correction must be very accurately determined and the readings for model in normal and inverted positions averaged in order to eliminate the effects of unsymmetrical air flow. The M. I. T. tests were purely routine, and as such did not include the precautions usually employed in a precision test. While the remaining data are in good agreement, it appears probable that the drag values are low for this reason.

III. Maximum $\frac{L}{D}$.—Using faired values altogether, the agreement in maximum L/D is very satisfactory. The extreme range is from 17.30 to 19.20, but if allowance be made for scale effect the deviation from a mean curve is relatively small, as shown on Figure 21.

IV. Ratio $\frac{C_{L\,max}}{C_{D\,min}}$.—This ratio is plotted against test speed in Figure 22. The extreme variation is from 73 to 84.6 if the M. I. T. value is included, or from 73 to 79.3 if the M. I. T. value is neglected. Again, part of the variation is due to scale effect as indicated by the dotted curve on Figure 21, which shows the expected trend.

V. Center of Pressure.—A large scale plot of center of pressure C_p against angle of attack is given on Figure 23. The Langley Field values at 20 and 30 meters per second and the McCook Field values at 20 miles per hour are in excellent agreement, while the Langley Field values at 10 meters per second are apparently about 1½ per cent to 2 per cent too far forward and the M. I. T. values at 40 miles per hour are apparently about 1½ per cent too far aft. Centers of pressure were not measured in the Bureau of Standards tests.

The agreement obtained is really quite satisfactory since a wire balance of the type used at Langley Field is rather unsatisfactory for measuring both forces and moments at low speeds.

CONCLUSIONS

A number of conclusions may be drawn from a study of these tests and while these conclusions are, in general, not new, it is considered desirable to give them as a general summary.

1. The Prandtl wall-effect correction is of great value. This correction should be incorporated in all published wind-tunnel data.

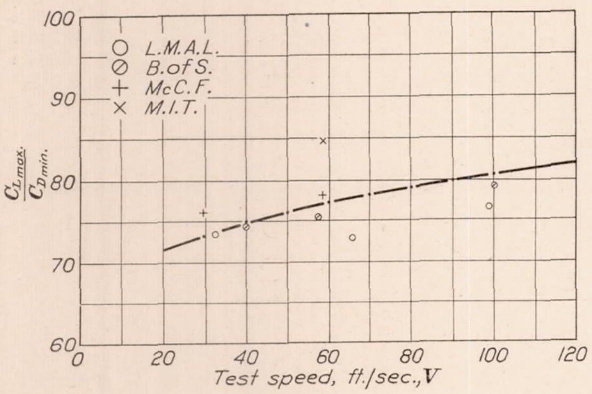

FIGURE 22

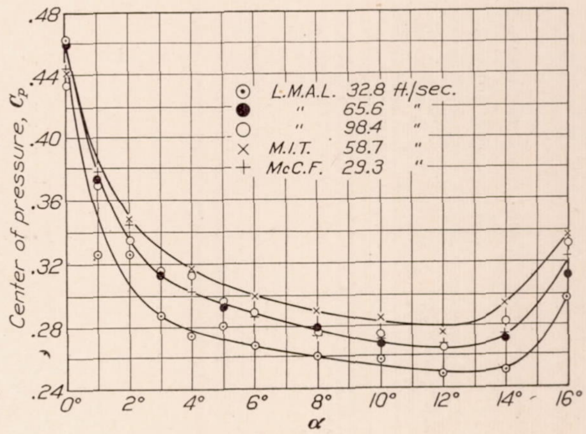

FIGURE 23

2. The agreement between the results from various wind tunnels, obtained in comparative tests of this type depends almost entirely on the care used in making the tests.

3. If accurate results are required, it is essential that all sources of error be investigated at each angle of attack. There is no assurance that a correction measured at one or two angles of attack can be interpolated or extrapolated.

4. The practice of testing an airfoil in both the upright and the inverted attitude and averaging the results should be made general.

5. During the last few years a very marked improvement in the quality of wind-tunnel test data has been made. The average routine test as now made is quite accurate for all design purposes.

6. These standardization tests should be of considerable interest and some value, but it is not likely that any similar additional series of tests would supply any new or valuable information. Such routine tests as are needed for standardization purposes can probably be handled most satisfactorily by agreement between the laboratories concerned.

ACKNOWLEDGMENT

The basic reports from which this analysis has been compiled were issued in various forms by the laboratories concerned. The report designations or descriptions and authors are as follows:

Bureau of Standards: The report from this laboratory entitled "Lift and Drag of Standard R. A. F. 15 Airfoil" was issued without designation of authors, but it is understood that these were Dr. H. L. Dryden and Mr. G. C. Hill.

Langley Memorial Aeronautical Laboratory: The test data from this laboratory are given in a report entitled "Tests of N. P. L. Standard Airfoil Model." The authors are not indicated but it is understood that these were Mr. E. G. Reid, Mr. A. J. Fairbanks, and Mr. E. D. Perkins.

Massachusetts Institute of Technology: The data from this laboratory are given in a report entitled "Report on Test of British International Trials Airfoil," Report Serial No. 204, by Mr. Shatswell Ober.

McCook Field: The data from this laboratory are given in a report entitled "Test in McCook Field Five-Foot Wind Tunnel of R. A. F. 15, 6 by 36 inch Airfoil (N. P. L. Metal Airfoil Circulated by N. A. C. A. for Wind Tunnel Standardization Tests)." This report is also designated as "Wind Tunnel Test No. 104" and is by Mr. E. N. Fales.

TABLES

TABLE I

Ordinates of 6 by 36 inch International Standard Airfoil as measured by the Gauge Section of the Bureau of Standards

Distance from L. E.	Section 12 inches from right tip		Section 16¼ inches from right tip		Section 24 inches from right tip		Standard R. A. F. 15	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Inches	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
0. 00	------	------	------	------	------	------	------	------
. 15	0. 238	0. 024	0. 234	0. 023	0. 232	0. 022	0. 2286	0. 0216
. 30	. 305	. 006	. 301	. 006	. 300	. 005	. 2970	. 0072
. 45	. 344	. 002	. 341	. 000	. 340	. 000	. 3360	. 0018
. 60	. 370	. 000	. 367	. 001	. 365	. 001	. 3606	. 0006
. 90	. 398	. 001	. 395	. 011	. 393	. 011	. 3900	. 0114
1. 20	. 410	. 026	. 407	. 026	. 405	. 025	. 4014	. 0258
1. 80	. 408	. 051	. 406	. 052	. 405	. 052	. 4014	. 0504
2. 40	. 394	. 047	. 391	. 048	. 390	. 048	. 3870	. 0480
3. 00	. 370	. 032	. 367	. 033	. 366	. 033	. 3642	. 0336
3. 60	. 337	. 012	. 334	. 012	. 334	. 011	. 3318	. 0126
4. 20	. 292	. 000	. 289	. 000	. 288	. 000	. 2886	. 0012
4. 80	. 238	. 001	. 234	. 003	. 235	. 001	. 2334	. 0018
5. 40	. 172	. 012	. 168	. 014	. 169	. 012	. 1704	. 0138

NOTE.—Ordinates given are the heights above a plane tangent to the lower surface.

TABLE II

International Standard R. A. F. 15 model, Bureau of Standards 10-foot wind tunnel, June, 1924

[Air speed, 40 feet per second]

α	C_L	C_D	L/D	Corrected for wall effect		
				α	C_D	L/D
−4	−0. 180	0. 0274	−6. 56	−4. 02	0. 0275	−6. 54
−2	−0. 033	. 0167	−1. 98	−2. 00	. 0167	−1. 98
0	+. 141	. 0143	9. 85	+. 02	. 0143	+9. 85
1	. 240	. 0157	15. 30	1. 03	. 0158	15. 20
2	. 328	. 0184	17. 82	2. 04	. 0187	17. 54
3	. 406	. 0221	18. 35	3. 06	. 0225	18. 03
4	. 475	. 0271	17. 50	4. 07	. 0276	17. 20
6	. 616	. 0385	16. 00	6. 08	. 0394	15. 62
8	. 762	. 0513	14. 85	8. 10	. 0527	14. 46
10	. 891	. 0708	12. 60	10. 12	. 0727	12. 23
12	. 995	. 0833	11. 93	12. 14	. 0857	11. 61
14	1. 051	. 1058	9. 95	14. 14	. 1085	9. 70

TABLE III

International Standard R. A. F. 15 model, Bureau of Standards, June, 1924

[Air speed, 57.5 feet per second]

α	C_L	C_D	L/D	Corrected for wall effect		
				α	C_D	L/D
−4	−0. 173	----------	----------	−4. 02	----------	----------
−2	−. 015	----------	----------	−2. 00	----------	----------
0	+. 168	0. 0141	+11. 91	+. 02	0. 0142	+11. 82
1	. 257	. 0152	16. 90	1. 04	. 0154	16. 68
2	. 336	. 0178	18. 86	2. 05	. 0181	18. 55
3	. 410	. 0216	18. 96	3. 06	. 0220	18. 63
4	. 481	. 0264	18. 22	4. 07	. 0270	17. 82
6	. 621	. 0379	16. 38	6. 09	. 0388	16. 00
8	. 778	. 0522	14. 90	8. 11	. 0537	14. 50
10	. 907	. 0681	13. 32	10. 12	. 0701	12. 94
12	1. 006	. 0828	12. 17	12. 14	. 0852	11. 84
14	1. 052	. 1053	9. 99	14. 14	. 1080	9. 74

TABLE IV

International Standard R. A. F. 15 Airfoil model, Bureau of Standards, June, 1924

[Air speed, 100 feet per second]

α	C_L	C_D	L/D	Corrected for wall effect		
				α	C_D	L/D
−4	−0. 173	----------	----------	−4. 02	----------	----------
−2	. 000	0. 0000	0. 00	−2. 00	----------	0. 00
0	+. 175	. 0140	+12. 50	. 02	0. 0141	+12. 41
1	. 262	. 0154	17. 00	1. 04	. 0156	16. 80
2	. 346	. 0185	18. 70	2. 05	. 0188	18. 40
3	. 430	. 0226	19. 00	3. 06	. 0230	18. 70
4	. 508	. 0277	18. 35	4. 07	. 0283	17. 96
6	. 658	. 0367	17. 93	6. 09	. 0377	17. 46
8	. 799	. 0492	16. 23	8. 11	. 0507	15. 80
10	. 935	. 0655	14. 28	10. 13	. 0676	13. 83
12	1. 059	. 0841	12. 60	12. 14	. 0868	12. 20
14	1. 093	----------	----------	14. 15	----------	----------

TABLE V

International Standard R. A. F. 15 Airfoil, Langley Memorial Aeronautical Laboratory 5-foot wind tunnel

[Test speed (10 meters per second), 32.8 feet per second]

α	C_L	C_D	L/D	C_p	Corrected for wall effect		
					α	C_D	L/D
−3	−0. 092	0. 0198	−4. 65	−4. 56	−3. 05	0. 0199	−4. 62
−2	−. 017	. 0173	−. 98	−. 851	−2. 01	. 0173	−. 98
−1	+. 052	. 0154	+3. 38	+. 760	−. 97	. 0154	+3. 38
0	. 142	. 0145	9. 79	. 462	+. 08	. 0147	9. 66
+1	. 248	. 0152	16. 32	. 326	1. 14	. 0157	15. 78
2	. 328	. 0178	18. 43	. 324	2. 18	. 0187	17. 54
3	. 403	. 0215	18. 76	. 287	3. 22	. 0230	17. 53
4	. 480	. 0257	18. 68	. 275	4. 26	. 0279	17. 20
5	. 555	. 0308	18. 00	. 281	5. 30	. 0338	16. 42
6	. 632	. 0368	17. 20	. 268	6. 35	. 0406	15. 58
8	. 781	. 0504	15. 50	. 261	8. 43	. 0563	13. 86
10	. 920	. 0665	13. 83	. 258	10. 50	. 0746	12. 33
12	1. 042	. 0843	12. 51	. 251	12. 57	. 0947	11. 00
14	1. 078	. 1199	9. 00	. 252	14. 58	. 1310	8. 23
16	1. 020	. 2181	4. 68	. 308	16. 56	. 2281	4. 47
18	. 947	. 3008	3. 15	. 354	18. 52	. 3095	3. 05

TABLE VI

International Standard R. A. F. 15 Airfoil, Langley Memorial Aeronautical Laboratory 5-foot wind tunnel, October, 1923

[Test speed (20 meters per second), 65.6 feet per second]

α	C_L	C_D	L/D	C_p	Corrected for wall effect		
					α	C_D	L/D
−3	−0. 088	0. 0189	−4. 66	−4. 04	−3. 05	0. 0190	−4. 63
−2	−. 008	. 0163	−. 49	−2. 27	−2. 00	. 0163	−. 49
−1	+. 080	. 0147	+5. 43	+. 620	−. 96	. 0148	+5. 41
0	. 167	. 0149	11. 20	. 460	+. 09	. 0152	10. 98
1	. 246	. 0163	15. 10	. 373	1. 13	. 0169	14. 55
2	. 322	. 0184	17. 50	. 336	2. 18	. 0194	16. 60
3	. 398	. 0211	18. 85	. 313	3. 22	. 0226	17. 60
4	. 472	. 0246	19. 18	. 305	4. 26	. 0267	17. 67
5	. 549	. 0291	18. 86	. 294	5. 30	. 0320	17. 16
6	. 626	. 0345	18. 14	. 289	6. 35	. 0382	16. 38
8	. 777	. 0470	16. 53	. 279	8. 43	. 0527	14. 72
10	. 917	. 0612	14. 96	. 269	10. 50	. 0692	13. 24
12	1. 014	. 0792	12. 80	. 267	12. 56	. 0890	11. 40
14	1. 069	. 1186	9. 01	. 272	14. 59	. 1295	8. 25
16	1. 050	. 2008	5. 22	. 311	16. 58	. 2113	4. 97
18	. 986	. 2788	3. 53	. 352	18. 54	. 2881	3. 42

TABLE VII

International Standard R. A. F. 15 Airfoil, Langley Memorial Aeronautical Laboratory 5-foot wind tunnel, October, 1923

[Test speed (30 meters per second), 98.4 feet per second]

α	C_L	C_D	L/D	C_p	Corrected for wall effect		
					α	C_D	L/D
−3	−0. 081	0. 0176	−4. 60	−5. 79	−3. 04	0. 0177	−4. 57
−2	+. 004	. 0149	+. 27	+9. 42	−1. 99	. 0149	+. 27
−1	. 096	. 0137	7. 04	. 593	−. 95	. 0138	6. 96
0	. 171	. 0144	11. 92	. 433	+. 09	. 0147	11. 60
1	. 240	. 0159	15. 13	. 370	1. 13	. 0165	14. 52
2	. 316	. 0174	18. 12	. 335	2. 17	. 0184	17. 17
3	. 394	. 0201	19. 57	. 315	3. 22	. 0216	18. 24
4	. 469	. 0238	19. 72	. 313	4. 26	. 0259	18. 11
5	. 547	. 0281	19. 44	. 296	5. 30	. 0309	17. 70
6	. 621	. 0329	18. 91	. 289	6. 34	. 0366	16. 97
8	. 771	. 0446	17. 32	. 278	8. 42	. 0503	15. 33
10	. 912	. 0588	15. 52	. 275	10. 50	. 0667	13. 67
12	1. 027	. 0779	13. 18	. 266	12. 56	. 0880	11. 67
14	1. 059	. 1206	8. 75	. 282	14. 58	. 1313	8. 07
16	1. 055	. 1805	5. 82	. 331	16. 58	. 1911	5. 52

TABLE VIII

International Standard R. A. F. 15 Airfoil model, Massachusettes Institute of Technology 7½-foot wind tunnel February, 1924

[Air speed, 58.67 feet per second.]

α	C_L	C_D	L/D	C_p	Corrected for wall effect		
					α	C_D	L/D
−4	−0. 144	0. 0210	−6. 85	----------	−4. 0	0. 0212	−6. 79
−2	−. 006	. 0138	−. 43	----------	−2. 0	. 0138	−. 43
0	+. 176	. 0122	+14. 42	0. 441	. 0	. 0124	+14. 09
2	. 328	. 0166	19. 76	. 348	+2. 1	. 0172	19. 17
4	. 472	. 0242	19. 50	. 317	4. 1	. 0252	18. 73
6	. 618	. 0346	17. 88	. 299	6. 2	. 0362	17. 07
8	. 758	. 0478	15. 86	. 289	8. 2	. 0502	15. 10
10	. 894	. 0634	14. 10	. 285	10. 2	. 0668	13. 38
12	1. 012	. 0810	12. 50	. 276	12. 2	. 0852	11. 88
14	1. 026	. 1154	8. 88	. 294	14. 3	. 1198	8. 56
16	. 976	. 1792	5. 44	. 336	16. 2	. 1840	5. 30
18	. 888	. 2608	3. 40	. 391	18. 2	. 2640	3. 36

TABLE IX

International Standard R. A. F. 15 Airfoil, McCook Field 5-foot wind tunnel, March, 1924

[Test speed (20 miles per hour), 29.3 feet per second]

α	C_L	C_D	L/D	C_p	Corrected for wall effect		
					α	C_D	L/D
−6	−0. 337	0. 0598	−5. 63	----------	−6. 19	0. 0608	−5. 54
−4	−. 152	. 0285	−5. 33	−5. 98	−4. 10	. 0287	−6. 11
−2	−. 033	. 0168	−1. 97	−. 463	−2. 02	. 0168	−1. 97
−1	+. 042	. 0156	+2. 68	. 822	−. 98	. 0156	+2. 68
0	. 131	. 0145	9. 03	. 443	+. 07	. 0146	8. 96
+1	. 242	. 0149	16. 22	. 379	1. 14	. 0154	15. 73
2	. 331	. 0184	18. 00	. 345	2. 19	. 0194	17. 00
4	. 483	. 0266	18. 16	. 303	4. 27	. 0289	16. 70
6	. 638	. 0371	17. 20	. 286	6. 36	. 0412	15. 50
8	. 785	. 0508	15. 48	. 275	8. 44	. 0568	13. 82
10	. 928	. 0693	13. 40	. 272	10. 52	. 0776	11. 97
12	1. 057	. 0859	12. 31	. 267	12. 60	. 0970	10. 89
14	1. 106	. 1329	8. 32	. 274	14. 62	. 1446	7. 65
16	1. 060	. 2325	4. 56	. 323	16. 60	. 2435	4. 35
18	1. 004	. 3000	3. 35	. 360	18. 57	. 3100	3. 24

TABLE X

International Standard R. A. F. 15 Airfoil, McCook Field 5-foot wind tunnel, March, 1924

[Test speed (40 miles per hour), 58.7 feet per second]

α	C_L	C_D	L/D	Corrected for wall effect		
				α	C_D	L/D
−6	−0. 329	0. 0589	−5. 58	−6. 18	0. 0599	−5. 50
−4	−. 174	. 0268	−6. 50	−4. 10	. 0271	−6. 42
−2	−. 012	. 0163	−7. 36	−2. 01	. 0163	−. 74
0	+. 187	. 0144	+12. 98	4. 11	. 0148	+12. 62
2	. 355	. 0188	18. 88	2. 20	. 0201	17. 68
4	. 510	. 0262	19. 46	2. 29	. 0275	18. 53
6	. 673	. 0370	18. 20	6. 38	. 0415	16. 20
8	. 826	. 0512	16. 10	8. 46	. 0577	14. 32
10	. 971	. 0687	14. 12	10. 55	. 0780	12. 45
12	1. 093	. 0921	11. 86	12. 62	. 1038	10. 53
14	1. 140	. 1296	8. 78	14. 64	. 1424	8. 00
16	1. 133	. 2120	5. 33	16. 64	. 2247	5. 05

TABLE XI

International Standard R. A. F. 15 Airfoil, summary of test data

Laboratory	Bureau of Standards		
Test speed, f. p. s.	40.0	57.5	100.0
$C_{L\ max}$	1.050	1.050	1.093
1. Data uncorrected for wall effect			
$C_{D\ min}$	.0140	.0138	.0137
L/D_{max}	18.40	19.10	19.10
$C_{L\ max}/C_{D\ min}$	75.0	76.1	79.8
2. Data corrected for wall effect			
$C_{D\ min}$	.0141	.0139	.0138
L/D_{max}	18.10	18.75	18.70
$C_{L\ max}/C_{D\ min}$	74.5	75.5	79.3
α for zero lift	−1.62	−1.84	−2.00

Laboratory	Langley Memorial Aeronautical Laboratory		
Test speed, f. p. s.	32.8	65.6	98.4
$C_{L\ max}$	1.083	1.073	1.057
1. Data uncorrected for wall effect			
$C_{D\ min}$	.0145	.0145	.0137
L/D_{max}	18.80	19.20	19.80
$C_{L\ max}/C_{D\ min}$	74.7	74.1	77.2
2. Data corrected for wall effect			
$C_{D\ min}$	.0147	.0147	.0138
L/D_{max}	17.60	17.75	18.30
$C_{L\ max}/C_{D\ min}$	73.7	73.0	76.6
α for zero lift	−1.75	−1.91	−1.96

Laboratory	Massachusetts Institute of Technology	McCook Field	
Test speed, f. p. s.	58.7	29.3	58.7
$C_{L\ max}$	1.040	1.110	1.153
1. Data uncorrected for wall effect			
$C_{D\ min}$	.0120	.0143	.0143
L/D_{max}	20.20	18.50	19.60
$C_{L\ max}/C_{D\ min}$	86.8	77.6	80.5
2. Data corrected for wall effect			
$C_{D\ min}$	.0123	.0146	.0147
L/D_{max}	19.20	17.30	18.60
$C_{L\ max}/C_{D\ min}$	84.6	76.0	78.3
α for zero lift	−1.94	−1.12	−1.90

BUREAU OF AERONAUTICS,
NAVY DEPARTMENT,
June, 1928.

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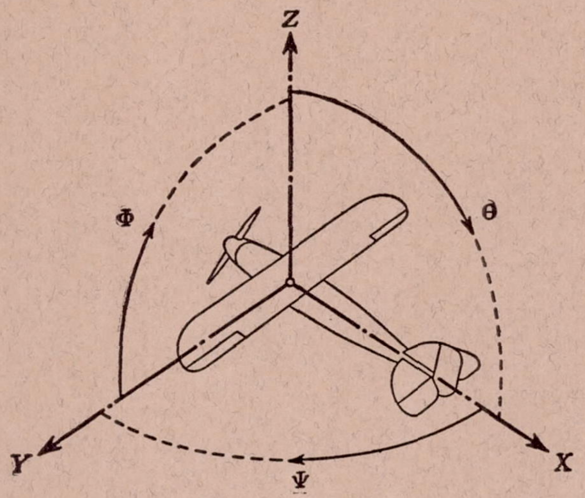

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.